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Numerical Modeling of Groundwater Flow in Daxing (Beijing), China

Q. C. Yang [a], J. Liang [b, c], Z. P. Yang [d], a*

[a] *Escuela de Ingenieros de Caminos, Universidad de A Coruña, Campus de Elviña, 15192, Spain*
[b] *Research Center for Eco-environmental Science, Chinese Academy of Sciences, Beijing, 100085, China*
[c] *Beijing Hydraulic Research Institute, Beijing, 100048, China*
[d] *College of Civil Engineering, Chongqing University, Chongqing 400045, China*

Abstract

The use of groundwater flow models is prevalent in the field of environmental hydrogeology. Models have been applied to investigate a wide variety of hydrogeological conditions. Recently, groundwater models have been applied to predict the fate and transport of contaminants for risk evaluation purposes. In this paper, a transient groundwater flow model in Daxing district of Beijing, China was developed. The conceptual model was built by analyzing the hydrogeological data. Hydraulic conductivities have been calibrated by the steady state model. The storage coefficients are calibrated by the transient model based on the available data observed from 1995 to 2000, which provides insights to understand the dynamic behavior of groundwater systems and to predict spatial-temporal distributions of groundwater levels in responding to changes. The model results help to identify the aquifer properties and to analyze the groundwater flow dynamics, the changes of groundwater levels, in addition, the improvement of the groundwater level monitoring network will be proposed through the analysis of groundwater levels. The calibrated transient model will be used later to predict the impacts of water resources management schemes on groundwater in the study area.

Keywords: Groundwater flow; Numerical model; Calibration; Transient model; Beijing

1. Introduction

Using groundwater flow models1 is prevalent in the field of environmental hydrogeology. Usually, groundwater flow models are used to calculate the rate and direction of movement of groundwater through aquifers and confining units in the subsurface. Numerous studies have been conducted in the last

* Corresponding author. Tel.: +34-981 167 000; fax: +34-981 167 170.
E-mail address: qyang@udc.es.

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decades using professional groundwater software, such as Visual MODFLOW, GMS, FEFLOW, SEAWAT, GSFLOW and/or the integration of some ones [1-4].

2. Description of the study area

The study area is located at the north of Beijing city, between north latitude 39.26° and 39.50°, east longitude 116.12° and 116.43°, about 45 m long and 42.7 m wide, and covers approximately 1030 km^2.

In Daxing district, the aquifer system is made of the Quaternary deposits and consists of predominantly stable continuous aquifers and discontinuous aquitard extending downwards to over 500 m below land surface (see Fig. 1). The deposits can be classified as pebble, sandy gravel, sand, fine sand and clay, which are the main water-bearing medium. The distribution of water resource decreased from the west to the east as well as from the north to the south. The thickness of Quaternary varies from tens to hundreds meters. The lithology of the aquifer system is complicated varying in sediment thickness and material compostions. From the alluvial fans to plain, the sediment thickness increases and grain size decreases, aquifer systems change from a single sandy gravel aquifer to multi-sand and clay layers.

Single sandy pebble zone: This zone is mainly distributed on the top part of the fluvial fan of rivers. The largest areas are distributed in Yongding River. Sandy pebbles appear generally 3 -5 meters below the land surface or exposed to the surface. The thickness of aquifer is variable spatially, from some 10 meter to more than 30 meters in Yongding River.

Two to three sandy gravel layers: This layer distributed on the mid-top of alluvial fans. Sandy gravel layers are alternated with clay layers. The aquifer is generally with a thickness of 30 to 50 meters. At the north of DaXing County, the aquifer thickness is more than 70 meters. Within these place, the lithology varies from coarse to fine and the aquifer type varies from phreatic to confined.

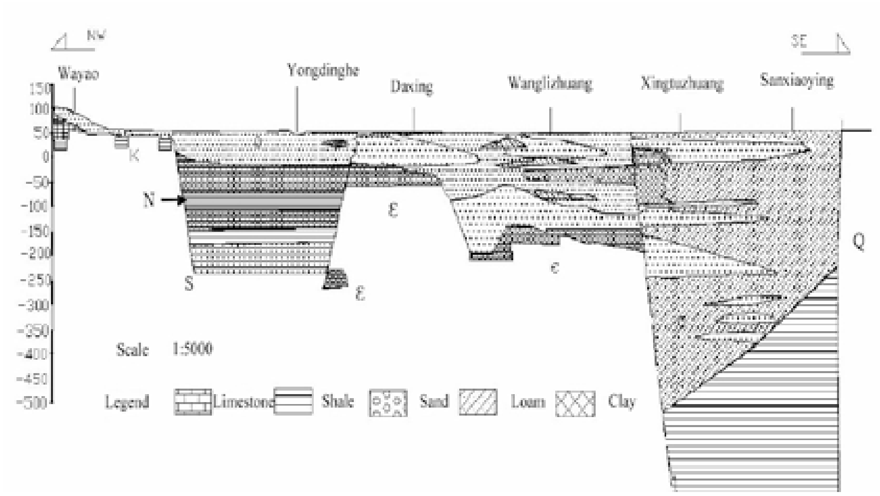

Fig. 1. WaYao-SanXiaoYing cross-section in Daxing district

Twelve cross-sections were created based on 500 borehole materials in the Beijing plain. Typical cross-sections in east-west (Fig. 1) show that from the top alluvial fans to plain, the aquifer system gradually transient from a thick single aquifer to multiple aquifer systems with alternating aquifer layers and aquitards. From analysis of all cross-sections it seems that a multiple aquifer system of 5 aquifers separated by 4 aquitards can represent the most areas of the Beijing Plain. At the top of alluvial fans aquitards are absent.

The main recharge sources in Daxing District are direct recharge from precipitation infiltration, surface water leakage (rivers and canal), lateral inflow from the district boundary, and return flow of irrigation. Recharge from precipitation: Precipitation directly infiltrated to groundwater by the small opening of loosen sediment and the fracture or solution cavity of the mountain rocks. It is the mainly resource of groundwater in Daxing District, it is estimated to be 148.73 million m^3 in 1989. Surface water leakage: at present, rivers become drier, so recharge from river leakage decreases gradually. Return flow of irrigation: There is nearly 50% extraction water for irrigation. With the improvement of irrigation tools and methods and change of vegetable, return flow of irrigation be affected slightly. The water level fluctuates significantly due to large evaporation and little precipitation in spring and excessive consumption of groundwater used for irrigation.

3. Numerical models

3.1. Aquifer system

The multiple aquifer systems were characterised as 2 aquifers separated by 2 aquitards and simulated in 4 model layers. The following information was used for schematizing: (a) constructing 5 longitudinal cross-sections along 5 rivers and 4 transversal cross-sections cutting through rivers and well fields; (b) plotting observation well locations on the cross-sections and checking differences in groundwater levels; (c) plotting pumping well locations on the cross-sections; (d) preparing scatter point data sets to interpolate layer elevations including x, y coordinates, surface elevation, average head, top of and bottom elevation of each layer. The schematic layered aquifer is represented in Fig. 2

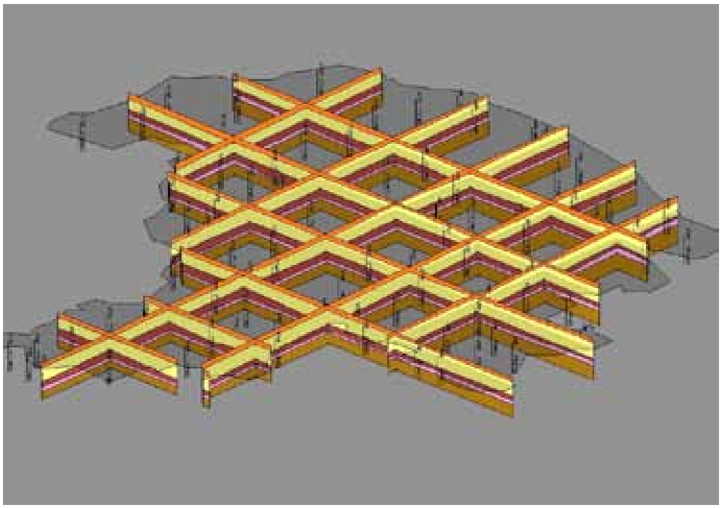

Fig. 2. Conceptual model layers i

3.2. Parameter zones

Parameter zones were defined based on types of porous media. Initial values of some large parameter zones are obtained from previous pumping test data and others are estimated values according to types of media. Steady state model calibration focused on the calibration of hydraulic conductivities.

3.3. Model calibration and verification

In this study, the transient simulation covers the period from 1995 to 2000. The stress period of 1 month was chosen which coincides with the observation interval of the groundwater heads in Beijing Plain. There are in total 72 stress periods for which time dependent inputs were specified.

Initial head of the each model layer came from the steady state head solution generated by the calibrated steady state model which formulated using the hydrological year of 1995. The use of model-generated head values ensures that the initial head data and the model hydrologic inputs and parameters are consistent.

Once all input data were prepared in a transient conceptual model, these data were automatically transferred to the transient numerical model. The transient numerical model was run from January 1995 to December 2000 to calculate monthly groundwater levels in 6 years. The calculated monthly groundwater level time series at locations of observation wells were compared with the observed monthly series. If the computed series did not fit to the observed series, the reasons were analyzed and storage parameters were adjusted. It was necessary to change the hydraulic conductivity, the steady state model was re-calibrated, and then the steady state heads were transferred to the transient model as the new initial conditions and the transient model was run again. This procedure was iterative until a good fit was achieved. Two wells were selected to represent the fitness between the computed values and measured ones.

We can observe from Fig. 3 that the general goodness of fit of the computed water heads and the measured ones except some discrepancies in some wells. The discrepancies is exist is some place due to the error comes from the steady state model. On the other hand, larger computed heads appear comparing to the observed heads attributed to the large discrepancies in the initial head. Somewhere, the abrupt larger discrepancy of head about 10 meters can be read, which maybe the observation error. Of course, carefully analysis and adjustment would be needed to implementing.

Annual total recharges and discharges were generated after the last calibration. The left part Fig. 4 demonstrates the annual total recharge from precipitation, return flow of irrigation, pipeline leakage and rivers and canal and so on. One can see that precipitation, return flow of irrigation and pipeline leakage are the main groundwater recharge, accounting for more than 50% of total annual recharge, followed by the rivers and canals and the N-W specific flow boundary, accounting for 30% to 40% of total annual recharge except in 1996 due to the large precipitation resolving by released water from Yong ding he river and Chaobaihe river in order to avoiding the flood resulting the largest recharge almost 1.65 billion m3 to groundwater. Over-exploitation of groundwater results in the depression cone which in turn changes the groundwater flow direction causing the inflow from the S-E boundary, which is the very little part of groundwater recharge in the study area no more than 3.5% of total annual recharge.

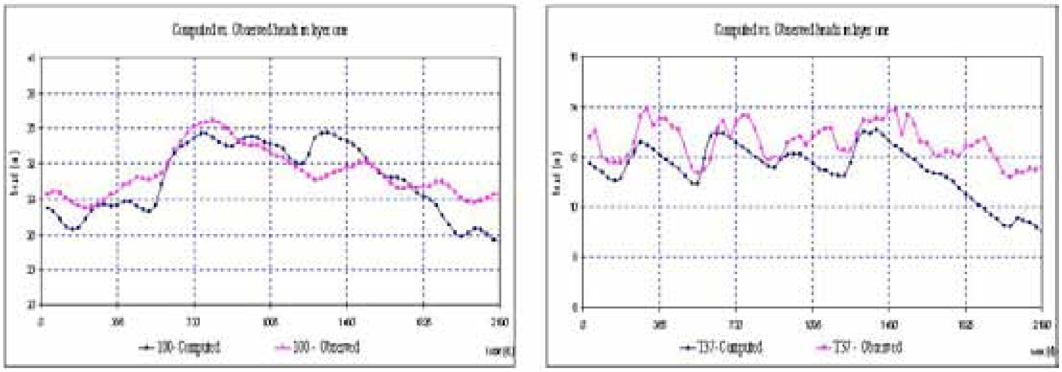

Fig. 3. Observed against computed groundwater levels in the transient model

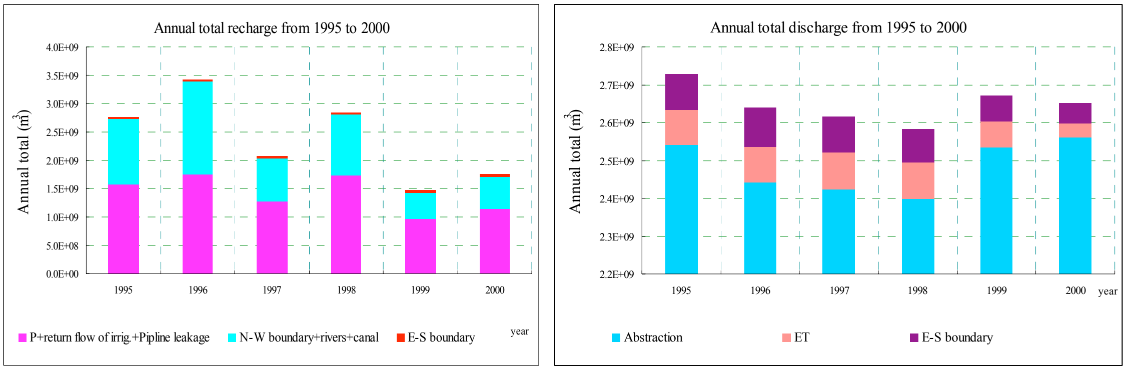

Fig.4. Annual component of recharge (left) and annual component of discharge from 1995 to 2000 (right)

The right part of Fig. 4 illustrates the simulated total annual discharge from 1995 to 2000, comprised by the artificial abstraction, ET and S-E general head boundary. It can be concluded that the dominated discharge of groundwater is the artificial abstraction occupying more than 90% of total annual discharge, which means the amount of artificial abstraction over 2.4 billion m^3 except 2.39 billion m^3 in 1998 resulting from the large precipitation in China. ET and S-E general head boundary play almost the same role in the groundwater discharge, accounting about 3.5% of total annual discharge respectively except no in 2000 with a value less than 53 million m^3 due to the continuous draught year in 1999 and 2000, which resulted in the abrupt decline of groundwater levels s more than 20 meters in some regions.

Fig. 5 demonstrates the simulated total annual discharge, recharge and change of storage from 1995 to 2000. We can observe that the maximum recharge in 1996, reached 3.4 billion m3, followed by 1998 with a value of 2.9 billion m^3, while the smallest recharge in 1999 only has 1.5 billion m^3, does not reach half recharge of 1996, therefore, a storage shortage occurred. And in the following year 2000, a quantity of1.8 billion m^3 is obtained, almost the half of the recharge of 1996, due to the temporal distribution of precipitation, all of these illustrated that the precipitation is the largest recharge source in study area. However, the annual total discharges nearly are constant reported from the Fig. 5 with a value of 2.5 billion m^3 in the whole simulated period. Combination of the annual total recharge lead to the largest shortage storage in 1999 over 1 billion m^3 and in 2000 near 1 billion m^3 which result in the decline of groundwater level significantly.

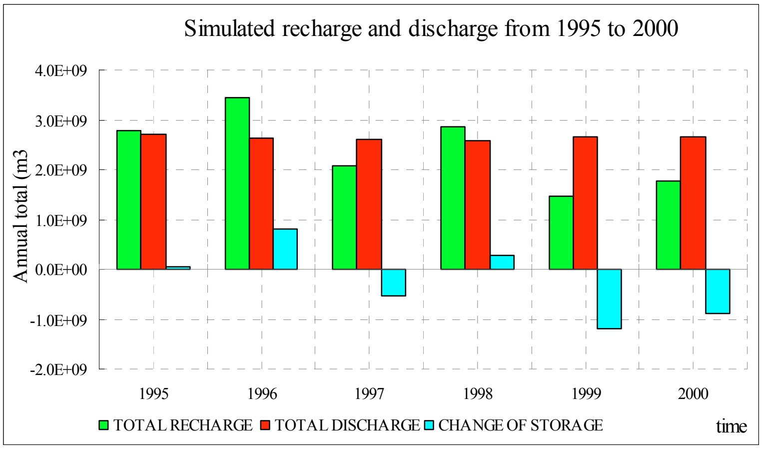

Fig. 5. Simulated recharge and discharge from 1995 to 2000

4. Conclusions and discussions

The main conclusions can be drawn from the numerical modeling of groundwater flow. Vertical downward flow is certified by groundwater levels at multiple piezometers in the area with multiple aquifers showing that groundwater level decrease. Not good correlation shown between monthly groundwater levels in alluvial fans and precipitation in several previous months. Other factors, such as groundwater abstraction and evaporation, should be considered to explain the change of groundwater levels. Main recharge of groundwater comes from direct precipitation infiltration followed by boundary inflow. River leakage has played less important roles since rivers are dry in most time; Artificial abstraction dominates groundwater discharge, groundwater seepage virtually ceased; Over-exploitation of groundwater has caused continuous decline of groundwater levels, resulting in the formation of the large core of depression and land subsidence; Groundwater in the deep confined aquifers comes mainly from the linkage of top shallow aquifers. Because the rate of linkage is small and slow, abstraction in the deep aquifers has caused the deepest core of depression. Single aquifer exists in the North-West boundary extending down to East-South boundary with multi-aquifers separated by the aquitard results the difference of water level in different layer. Flow directions conceptualized from the boundary to the depression cone.

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